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STUDY OF FLIGHT MANAGEMENT REQUIREMENTS DURING SST LOW VISIBILITY APPROACH AND LANDING OPERATIONS

VOLUME III:

Recommendations for a Simulation Research Study of Selected Flight Management Support Problems

June 1968

Prepared by:

Walter B. Gartner

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INTRODUCTION

In an earlier phase of the study reported in this document (ref. 1), a number of potential problems in supporting SST command pilots in the performance of flight management tasks during low visibility approach and landing operations were identified and discussed. Flight management tasks found to impose unrealistic information processing demands on the Captain or considered especially vulnerable to the effects of time constraints on task performance or limitations in the quality of available information were distinguished in an analysis of cognitive task loading. The identification, in this analysis, of anticipated difficulties, uncertainties, and lack of clear structure in information processing descriptions of component diagnostic and action decision activities provided the basis for distinguishing inadequately supported flight management tasks. In the course of this analysis, consideration was also given to crew acceptance and human engineering problems.

Available literature on pertinent developments in all weather landing systems for commercial jet transports and on the proposed design features of an approach and landing system for the United States SST was used extensively in the development of this analysis. In many instances, supporting data and arguments derived from closely related simulation studies and flight test programs could be applied to problem statements addressed to flight management in projected SST operations. However, since these problem statements were the product of a logical analysis, more directly applicable empirical study is considered necessary in order to provide additional verification and to resolve the issued raised.

From the outset, the present study has been directed toward the identification of specific research objectives within this problem area which can be met using the jet transport simulation capabilities at the NASA Ames Research Center. Accordingly, the final phase of the study has been concerned with the selection of problem statements for further empirical study using Ames simulation facilities and with the preparation of detailed recommendations for a simulation study. This report presents the general approach adopted for an investigation of selected flight management problems in the piloted flight simulator and provides a detailed plan for carrying out initial studies.

The first section of the report sets forth the specific information objectives of the recommended simulation study and provides a brief restatement of the selected problems. An overview of the structure of the study is then presented in order to outline the general plan of attack on these problems and the rationale for proceeding in this way. In subsequent sections, the details of this study plan are delineated and certain key simulation requirements to be satisfied in the implementation of the study are discussed. Consideration is given to the defining characteristics of the simulated flight sequence, controlled variations in environmental conditions to be represented, tasks to be assigned to subject-pilots, subject selection requirements and orientation to task performance, and the experimental design underlying recommended data collection and analysis activities. Requirements for adequately simulating SST information availability and display characteristics and automatic control of ILS tracking and airspeed are then discussed.

SIMULATION STUDY OBJECTIVES AND GENERAL APPROACH

Fourteen potential problem areas were distinguished as a result of the analysis carried out in the second phase of this study (ref. 1). Insofar as support for flight management activities is concerned, each of these problem areas represents a possible inadequacy in the SST landing system design features and/or operational procedures assumed as the reference system in the analysis. To the extent that comparable system design features and procedures are also characteristic of low visibility landing systems under development or currently being certified for other jet transports, including operational subsonic aircraft, these problem statements are also applicable outside of the SST context. Despite active and increasingly extensive research and development programs in support of low visibility landing systems, the issues raised in these problem statements remain largely unresolved.

An ongoing simulation research program designed to provide an empirical assessment of suspect system design features and procedures and, subsequently, to develop and test solution concepts for empirically verified problem areas is recommended. The long term objectives of this program would be to obtain empirical confirmation or disconfirmation of each of the problem statements, to isolate the specific system design features and/or procedures which appear to be the source of these problems, and to identify and test desired changes and/or new developments in system design and operating techniques.

As an initial effort in setting up this program, a piloted flight simulator study of selected problem statements is recommended. The limited scope and objectives of this initial study will allow for the gradual development of the simulation equipment capability and techniques which are peculiar to the assessment of flight management task performance and, at the same time, provide data on the selected issues. Both of these products are needed to guide the design and implementation of subsequent studies.

Problems Selected for Initial Study

Two major considerations influenced the selection of problem areas for initial investigation in the recommended simulation program. First, it was decided that problems peculiar to Category II operating conditions, and preferably those applicable to current subsonic jet transport operations as well as to the SST, were to be considered early in the program. A number of system configurations have already been certified for Category II operations and data on potential operating problems, if any, should be made available as soon as possible if it can be expected to affect the development and use of these systems. Further, these developments can be expected to be a significant factor in the subsequent derivation of Category III system design concepts and operating criteria which are not yet formally specified.

The second consideration is that it is desirable, for initial investigations, to select problems which can be examined without imposing extensive demands on simulation equipment capability. At the time of this writing, full capability for simulating all SST crew stations and all of the flight deck instrumentation, external visual effects, environmental conditions, etc., which may affect flight management are not available in Ames simulation facilities. This is understandable, since comprehensive requirements for simulation studies in this area have not previously been defined. Beginning with the recommended initial studies, however, the additional capabilities required can be built up as they are needed and this development can be guided by experiences gained with the more austere facilities.

These general constraints were satisfied by selecting potential flight management problems associated with judging approach success as the focus of initial study efforts. In the baseline Low Visibility Landing

System (LVLS), suspect components of this flight management activity are performed, primarily, by reference to conventional flight instruments. Representation of SST-peculiar aircraft dynamics and flight deck design concepts in the simulation is, of course, desirable, but it is not considered essential to the derivation of useful data in the simulation study. The results of this initial study could therefore be applicable to Category II operations and to appropriately equipped subsonic jet transports as well as to the baseline SST system. At the same time, minimum demands would be imposed on the simulation facility, since no complex display of extra-cockpit visual cues is required and no advanced display concepts need be represented in initial simulation sequences.

The general objective of the intial study will be to exercise subject-pilots in the performance of approach assessment tasks, under nominal Category II operating conditions, and to determine how well they are supported in the performance of these tasks by the SST information availability and display characteristics assumed for the baseline LVLS. Suspect approach assessment tasks include the assessment of relative altitude, flight path alignment with the runway, and vertical flight path alignment as the aircraft approaches the Category II decision height. The initial study is also designed to explore some of the factors which are expected to affect the performance of approach success judgments and to determine the effects of these factors on the accuracy, reliability, and/or timeliness of component assessment tasks. A more complete discussion of the objectives of the intial study and the approach to be taken is given in the next section.

General Plan of Attack

The principal objective of the recommended simulation study is to determine the accuracy, timeliness, and reliability of component judgments of approach success during a dynamic simulation of the Category II approach and landing sequence. During these simulated flight sequences, it will be of critical importance to control the subject-pilot's orientation toward task performance, the information available to him for assessing the ongoing flight situation, and manner in which this information is displayed. The general intent of these controls is to ensure that the information processing demands of the experimental task do not differ in any significant way from those envisioned for the actual tasks in the baseline SST landing system. A more complete explication of this control requirement is given in the subsequent delineation of the experimental plan and in the identification of simulation requirements. To the extent that this key control requirement can be satisfied in the simulation sequence, data obtained on the subject's performance of assigned flight management tasks can be used to confirm or disconfirm the selected problem statements and thus forecast difficulties, if any, in supporting flight management task performance in the projected baseline system.

In order to exploit this basic experimental situation to obtain additional data, the study will also be designed to examine the effects of alternative crew procedures and control task loadings on flight management task performance and to examine landing performance from various flight path offset conditions at the decision height. Variations in crew procedures can be distinguished by citing differences in the pre-arranged assignment of specific monitoring and/or control duties to the Captain and First Officer. It is reasonable to assume that flight management performance would be differentially affected by such variations, since the immediate bases for making the approach success judgments, in terms of information available and display modes, will not be the same when alternative crew procedures are adopted. Alternative flight control modes, i.e., fully automatic, split-axis control, and fully manual, will be examined to disclose the effects, if any, of differences in task loading on the Captain. When manual control is assumed for one or more axes, the Captain can be expected to have less time and attention to apply to flight management tasks, per se.

The basic design of the study, then, can be understood as a test of the extent to which the information environment projected for the baseline SST landing system may be expected to support the Captain in his assessment of approach success. For the most part, this information environment is comprised of flight deck instruments and auditory display channels (e.g., aural warning signals and radio voice communications), and study results would thus apply primarily to the selection or development of these landing system components. But the information environment also includes such information sources as flight planning and in-flight reference materials (e.g., clearances, approach charts, flight data sheets, etc.), the air and ground environment, and even learned procedures and perceptual expectancies. The influence of these additional information sources on flight management task performance must also be considered in the simulation study.

It should be clear that the study is not intended, in any sense, to evaluate the quality of individual pilot-subject's judgmental or decision making abilities. Indeed, the recommended experimental plan will give explicit consideration to controlling the effects of individual differences in subject skills in this area. Moreover, subject-pilots will be asked to provide critical evaluations of the information and display characteristics available to them in the simulation, in much the same way that expert opinion judgments and preference data are obtained in aircraft handling qualities investigations. The subject's primary role, of course, will be to carry out the assigned approach management and landing control tasks in accordance with the orientation given. Insofar as this is feasible then, subject selection and orientation to the experimental task will be directed toward achieving behavior in the simulator that is representative of the behavior of SST command pilots in an actual operational situation.

The structure of the recommended study is schematized in Figure 1. Each run in the simulator will represent the execution of an approach and landing sequence beginning with the aircraft at approximately ten nautical miles from the runway, stabilized on the assigned localizer course, and maintaining an assigned initial approach altitude. This sequence ends with the aircraft on the runway decelerating to a nominal turn-off speed or with the subject pilot's decision to reject the approach and initiate a go-around. During this simulated flight sequence, subjects will perform specified flight management tasks, responding to simulated information inputs representing the ongoing flight situation as they would be available to command pilots in the projected SST operational environment. The intent here is to impose the same information processing demands on subjects in the simulation as those associated with the performance of specified tasks in the operational situation. For this reason, both the information provided and the display characteristics (i.e., presentation mode, type of display, and, in some instances, display-referent relationships) must match their assumed counterparts in the baseline SST system.

On each run, data on subject performance will be recorded as indicated by the subject outputs shown in Figure 1. At the same time, data will be recorded on the "actual" position and behavior of the aircraft as represented in simulation sequence and, where appropriate, on the corresponding display of flight situation parameters which, presumably, will serve as the immediate basis for subject judgments. These data, together with the results of subjective data obtained from subjects following their participation in the simulation exercise, will then be available for analysis and interpretation as appropriate to the objectives of the study.

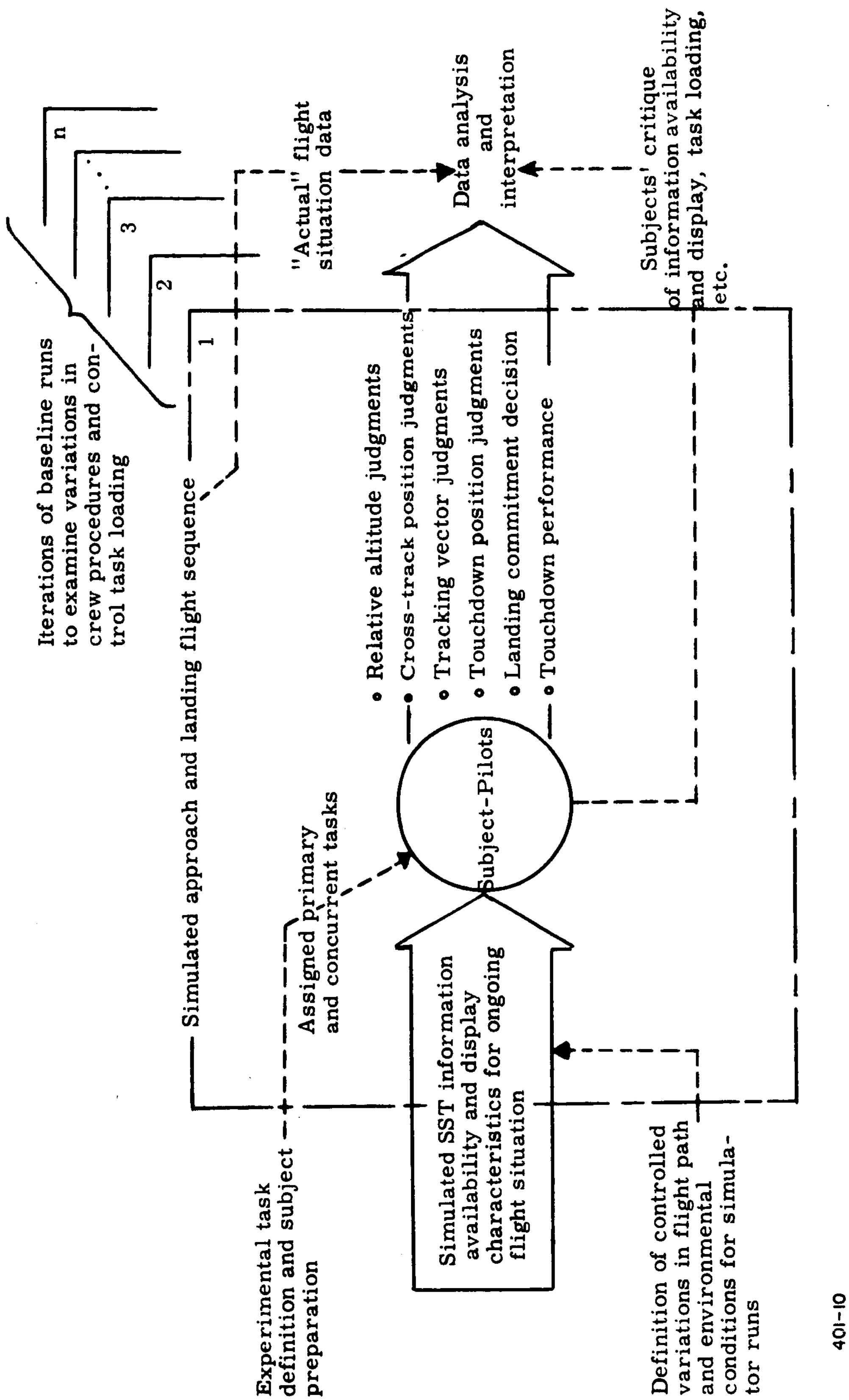

Figure 1. Schematic representation of the overall structure of the recommended simulation study.

Notice that simulated information inputs, subject task assignments, and the data taken will be held constant on all simulated runs. Controlled variations in the flight path actually followed (e.g., ILS deviation, actual lateral and vertical offset position at the decision height, etc.) and environmental conditions (e.g., terrain profiles approaching the decision height, wind conditions, break-out height, etc.) will be represented in the information inputs in order to include a number of different flight situations for subjects to respond to. A systematic assignment of these variable conditions to simulation runs will be worked out to ensure an appropriate sampling of conditions of interest.

Baseline runs will be conducted with a fully-coupled automatic flight control mode simulated and, somewhat arbitrarily, adopting a crew procedure wherein the Captain exercises complete control of the approach to the decision height. As the aircraft approaches the decision height, the Captain has the option of looking up to assess the adequacy of external visual reference at any time. Based on this assessment and, at his discretion, on the additional cross-checking of flight instruments, he would then resolve the landing commitment decision and either abort the approach or assume manual control to complete the landing maneuver. As indicated in Figure 1, iterations of the baseline scheme will be carried-out to examine the effects of alternative flight control modes and crew procedures. The structure of the study, as schematized, will be essentially unchanged in these iterations, but in each of the iterations a different combination of control mode and crew procedure would govern the subject's task orientation and the simulation of the flight sequence.

Each element of the study schematized in Figure 1 is considered in more detail in the experimental plan outlined in the next section. The intent of the foregoing discussion is to provide an overview of the structure of the recommended study and the general sense of conducting the study in this way. This study concept was used to guide the development of the plan which follows and will in turn guide the subsequent specification of means for the actual set-up and conduct of the study.

EXPERIMENTAL PLAN

Simulated Approach and Landing Flight Sequence

The operational context adopted as a framework for the experimental manipulations in the recommended study is a Category II approach and landing sequence. For convenience, the recently published Category II approach to runway 1R at Dulles International Airport (DIA) was selected to define the assigned flight profile and will be used on all simulation runs as the reference profile. The current Approach Chart for this profile is reproduced in Figure 2. Specific features of the simulation profile, which may differ from those shown in Figure 2, and descriptions of simulated flight paths will be made with reference to this approach.

Controlled Variations in Flight Profiles

Since the principal concern of the simulation sequence is to exercise subjects in specified approach assessment tasks, it is desirable to include a number of different flight situations for them to judge. The key parameters on which the approach will be assessed are:

1. Vertical offset (actual glide slope deviation in feet),

2. Lateral offset (cross-track error in feet), and

3. Tracking vector (alignment of the aircraft's horizontal flight path with the localizer course, i.e., parallel, converging, or diverging), as the aircraft approaches the decision height.

By systematically varying the values assigned to these parameters on any given run and providing for reasonable variations in flight path control earlier in the approach, ten different profiles can be defined to cover all

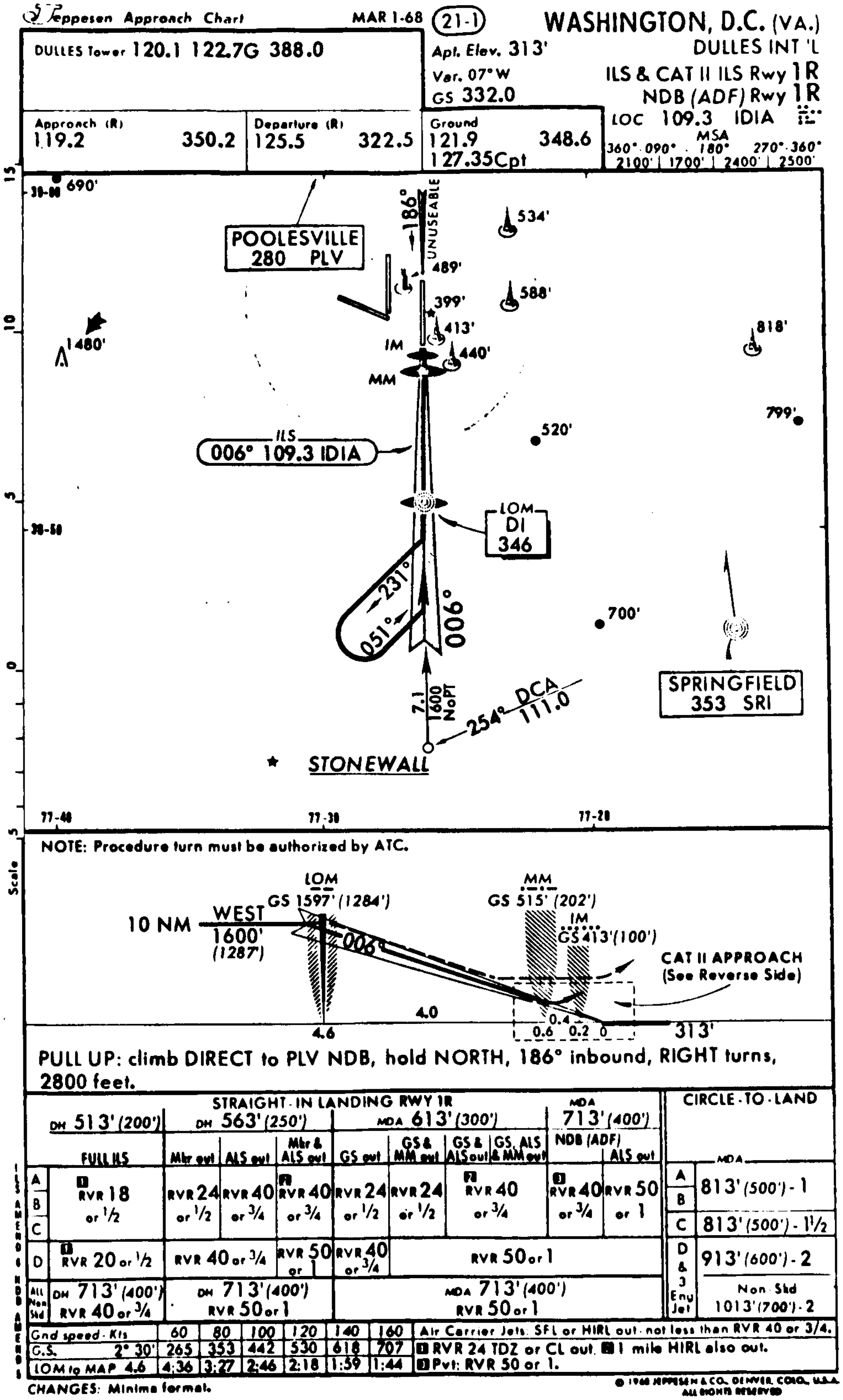

Figure 2a. Initial segment of Category II approach profile for DIA.

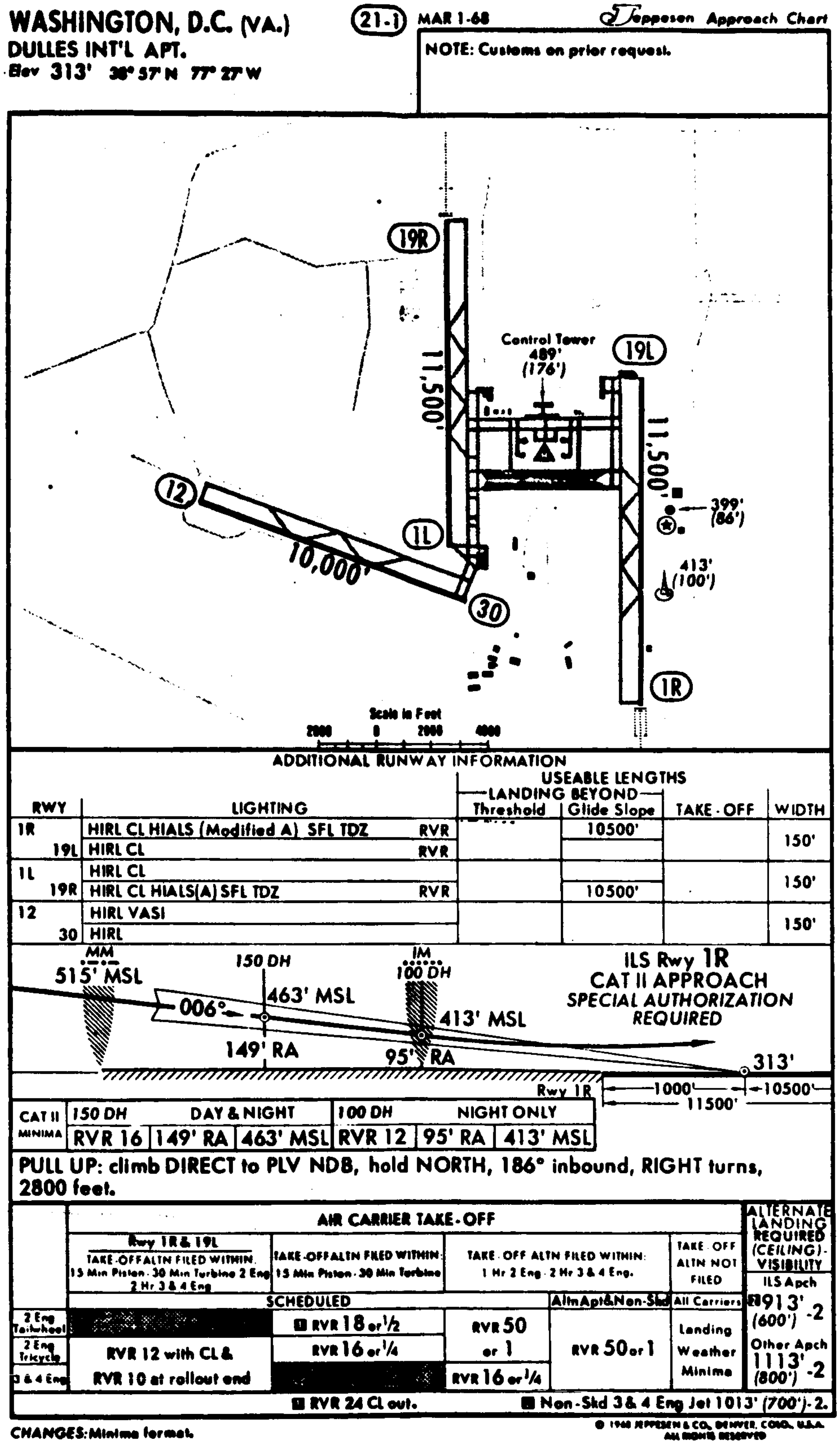

Figure 2b. Final segment of Category II approach profile for DIA

of the different flight situations which might be of interest in the study. Nine of these profiles are defined in Table 1 by combining three vertical offset conditions ("on", "high", and "low")with three lateral offset conditions ("on", "marginal", and "excessive") and three tracking vector conditions ("parallel", "converging", and "diverging"). Each of these combinations defines a different flight situation at the decision height and may thus be construed as the "terminal condition" for a given approach. One of three possible variations in approach history is associated with each of these terminal conditions: a "cross-over" flight path defined by sinusoidal variations around the assigned profile, a consistent tendency to be either "high" or "low" on the glide slope, or a consistent tendency to be to the "right" or "left" of the localizer course. These profiles are more precisely defined in Figure 3 (a through g) from which actual values of these flight path-defining parameters can be read.

A tenth profile has been identified in Table 1 as a reminder that the controlled variations in simulated flight paths called for in profiles P-1 through P-9 can be generated only on simulation runs for which the automatic flight control mode is specified. On some runs, manual control will be exercised on one or more axes and the corresponding fligh path parameters (i.e., vertical offset when pitch axis control is manual, lateral offset and tracking vectors when control of the roll axis is also manual) would, of course, assume whatever values resulted from the subject's performance of the control task.

The intended application of the profiles defined in Figure 3 in the recommended study is, as already indicated, to exercise the subjects in judging a wider range of flight situations than would be the case if only "typical" or "in-tolerance" runs were simulated. For this reason, excessive deviations from optimum control system performance are deliberately included without regard to the probability of their actual occurrence in the operational situation. The intent is simply to include some marginal and

Table 1. Definition of Alternative Flight Profiles for Controlled Simulation Sequences

	Terminal Condition			Approach History	
Profile Designator	Vertical Offset	Lateral Offset	Tracking Vector	Glide Slope Tracking	Localizer Tracking
P-1	on	on	parallel	cross-over	cross-over
P-2	on	marginal	diverging	high	left
P-3	on	excessive	converging	low	right
P-4	high	on	diverging	cross-over	right
P-5	high	marginal	converging	high	cross-over
P-6	high	excessive	parallel	low	left
P-7	low	on	converging	cross-over	left
P-8	low	marginal	parallel	high	right
P-9	low	excessive	diverging	low	cross-over
P-10	As attained by manual flight path control				

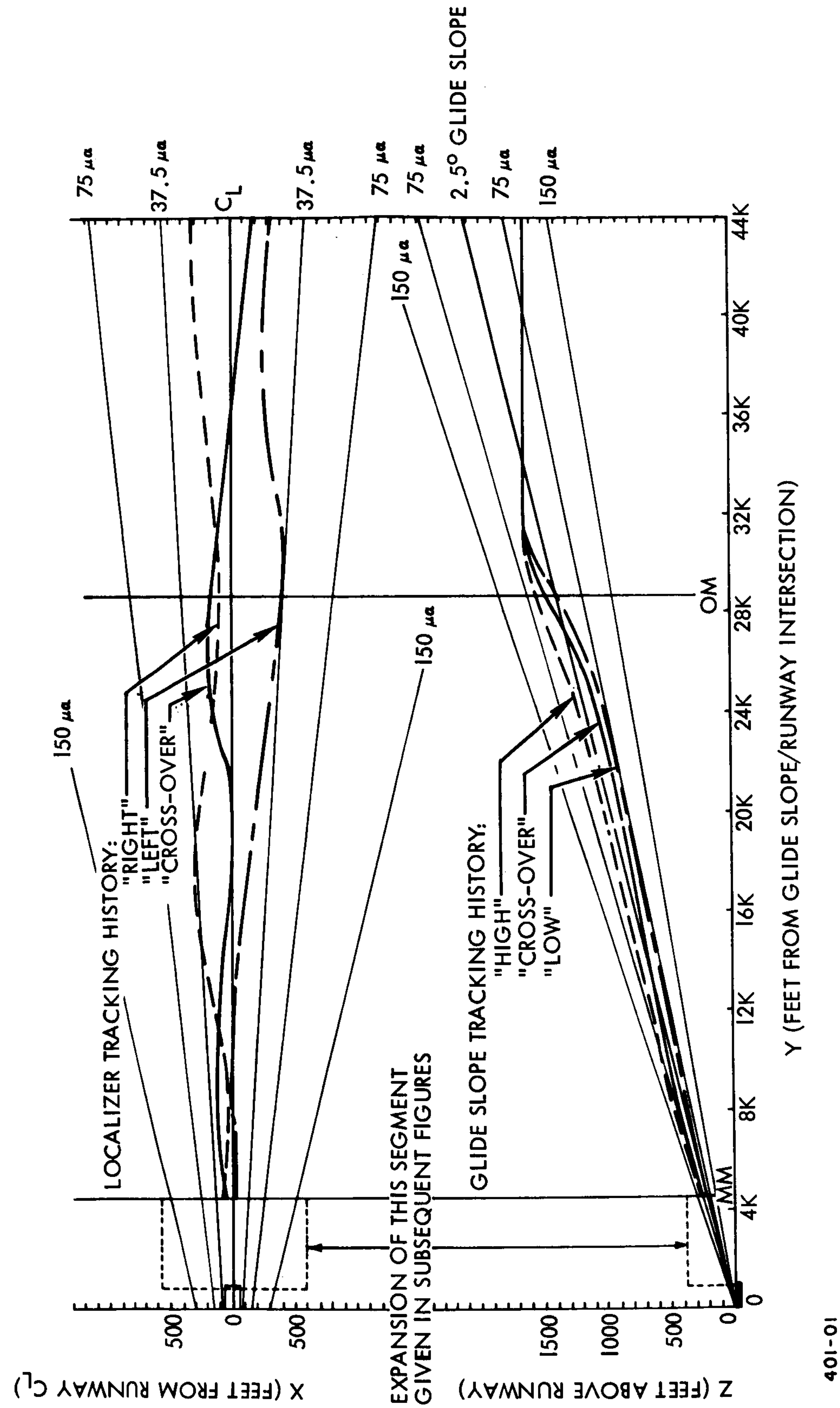

Figure 3a. Variations in approach history for controlled flight sequence simulations. Localizer and glide slope deviation signal strength is given in micro-amperes (ua).

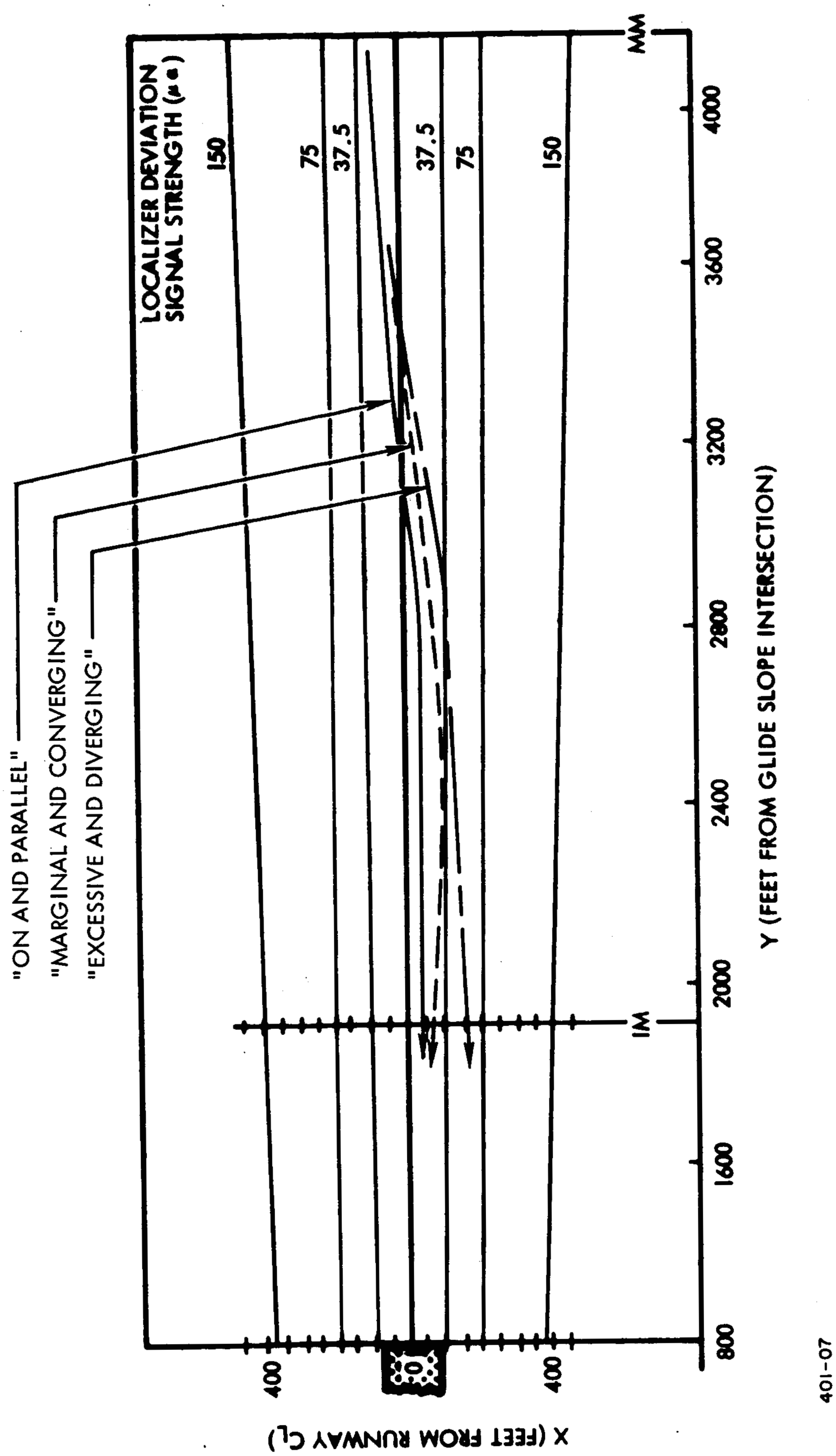

Figure 3b. Variations in lateral offset associated with a "Cross-over" localizer tracking history.

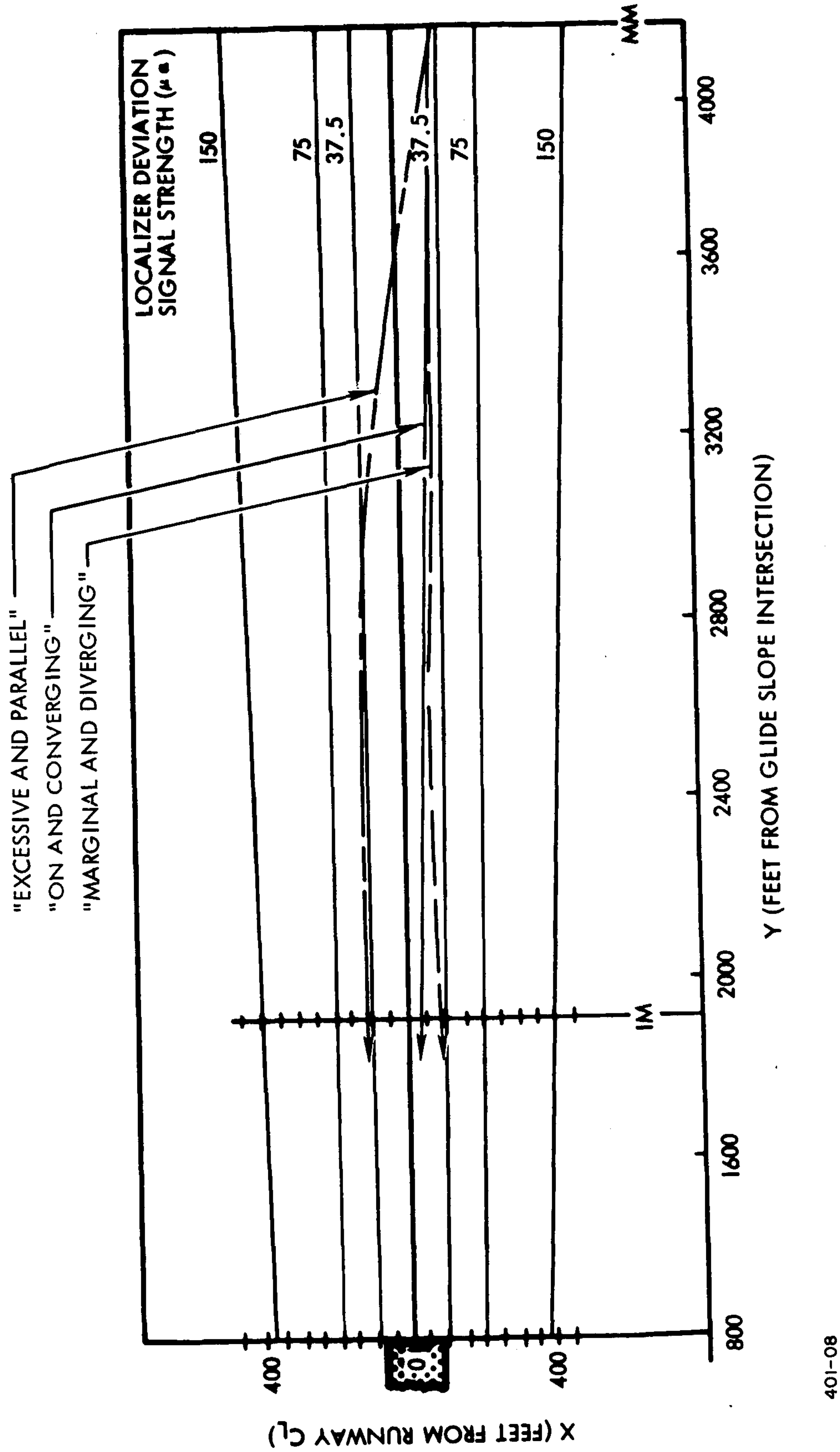

Figure 3c. Variations in lateral offset associated with a "Left" localizer tracking history.

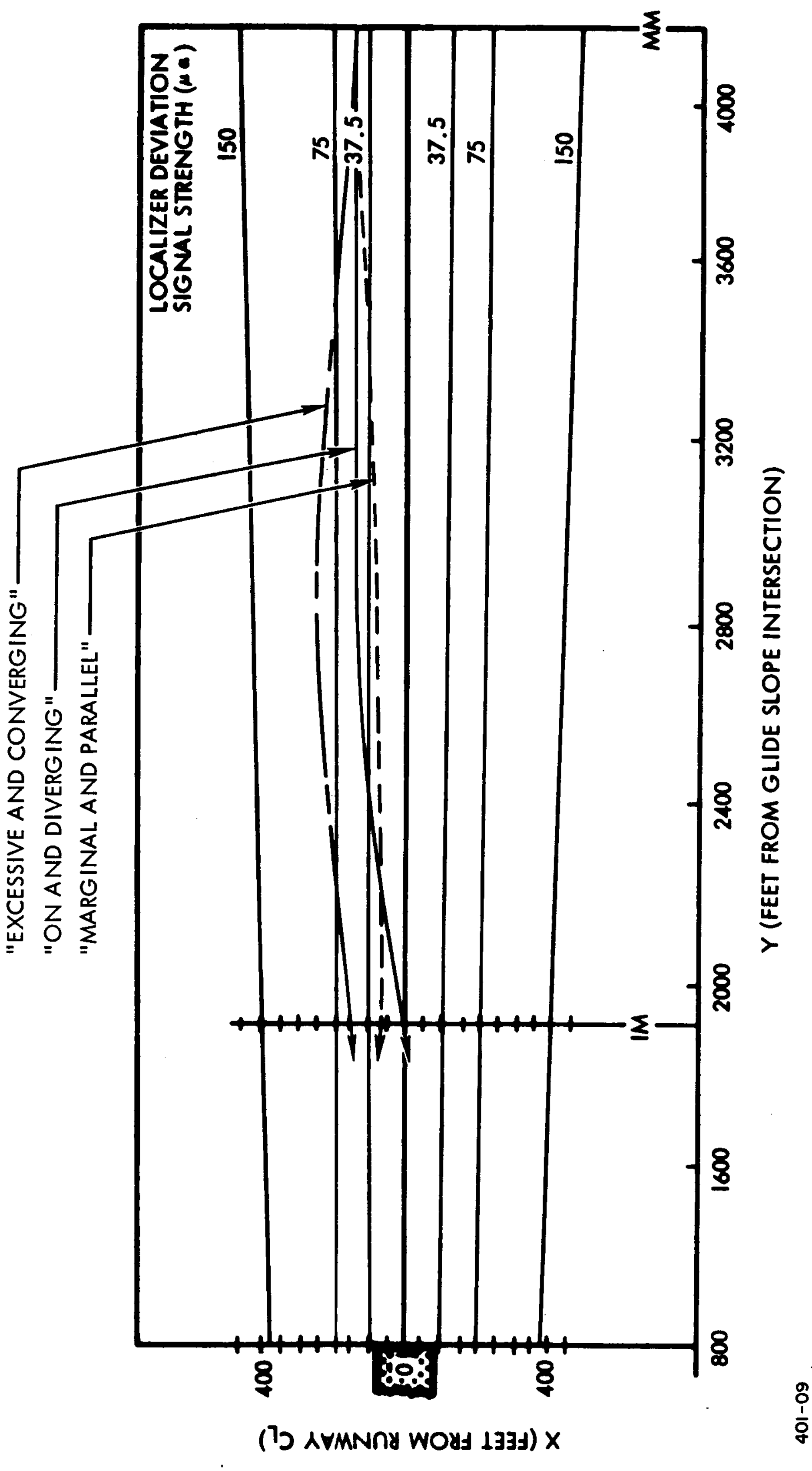

Figure 3d. Variations in lateral offset associated with a "Right" localizer tracking history.

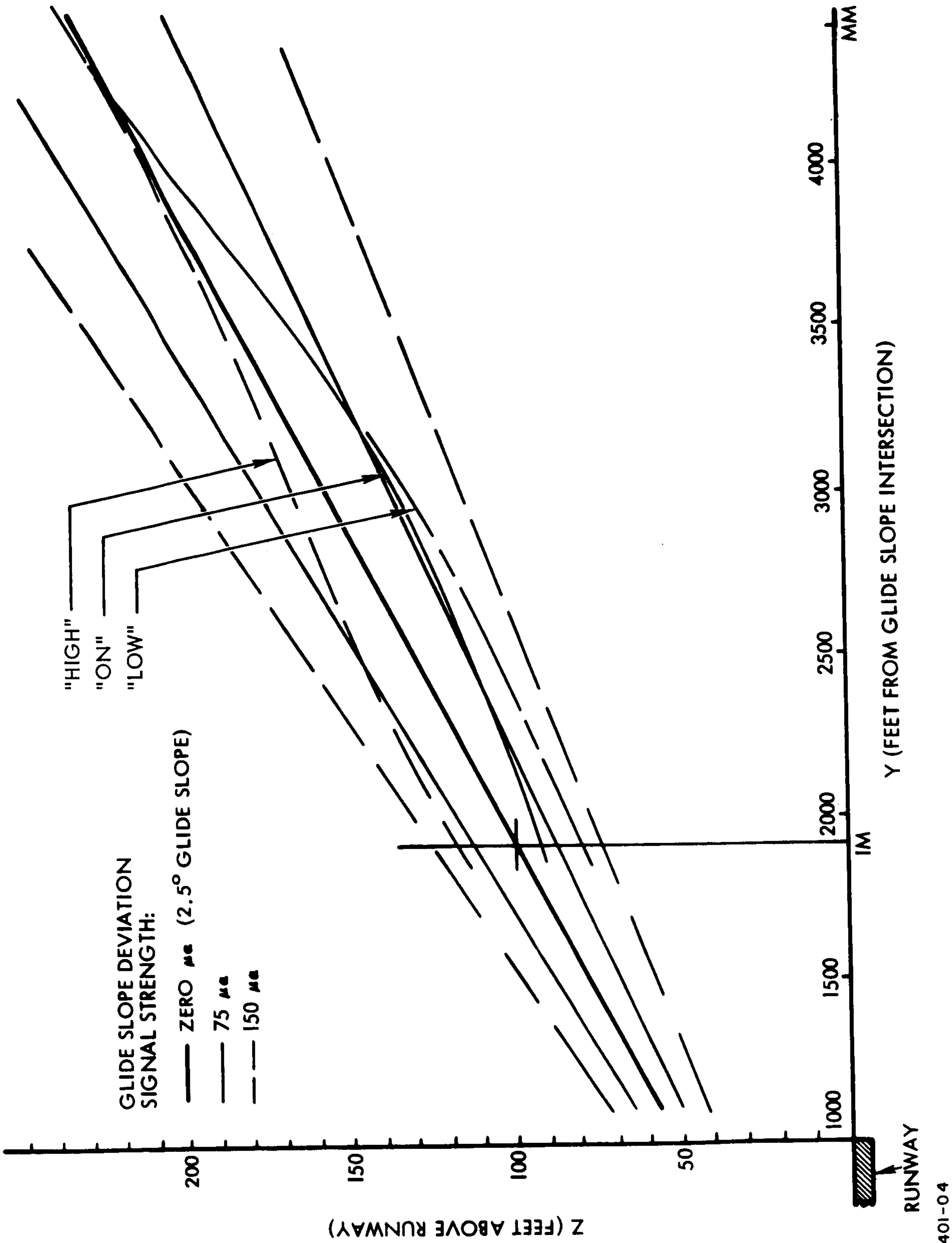

Figure 3e. Variations in vertical offset associated with a "Cross-over" glide slope tracking history.

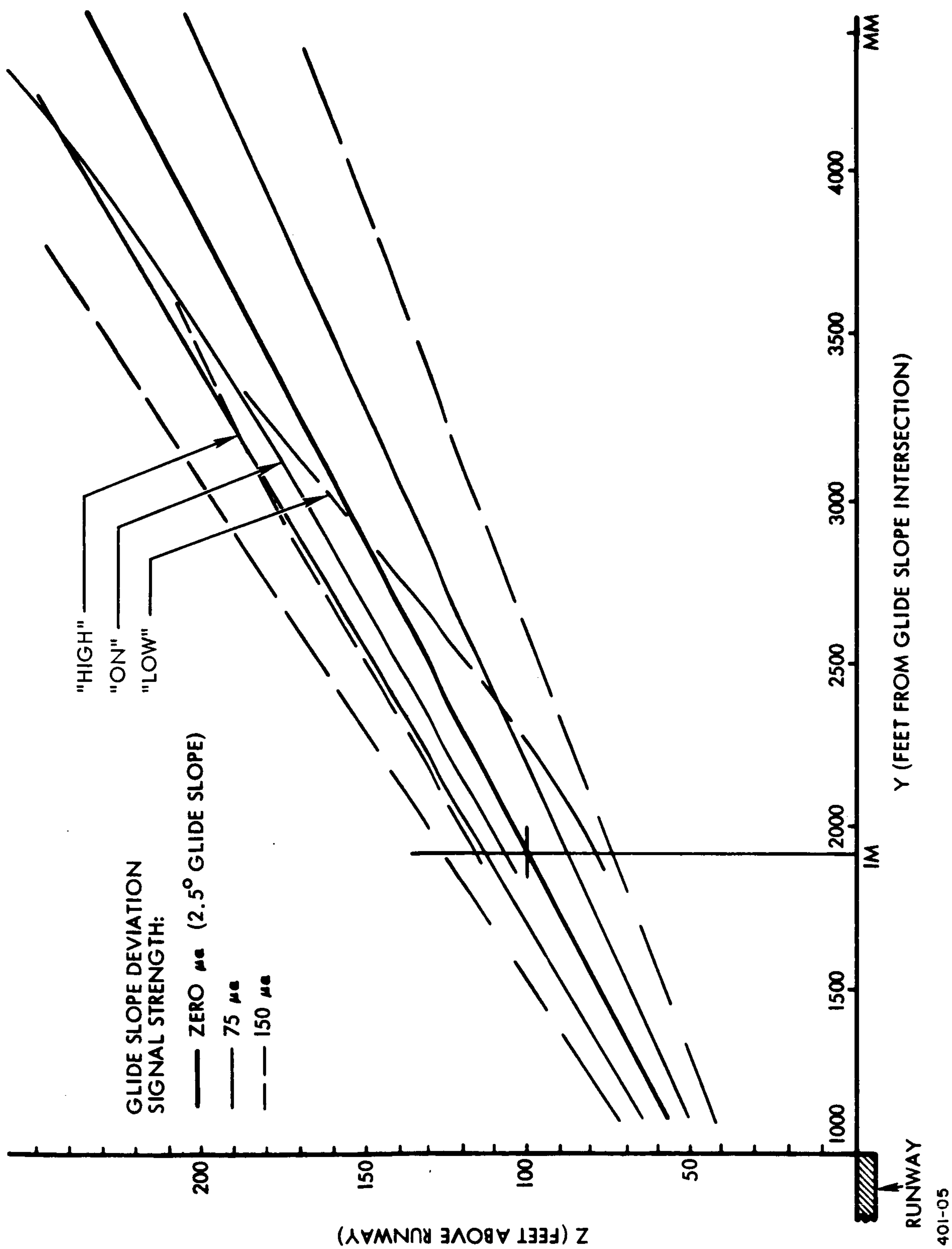

Figure 3f. Variations in vertical offset associated with a "High" glide slope tracking history.

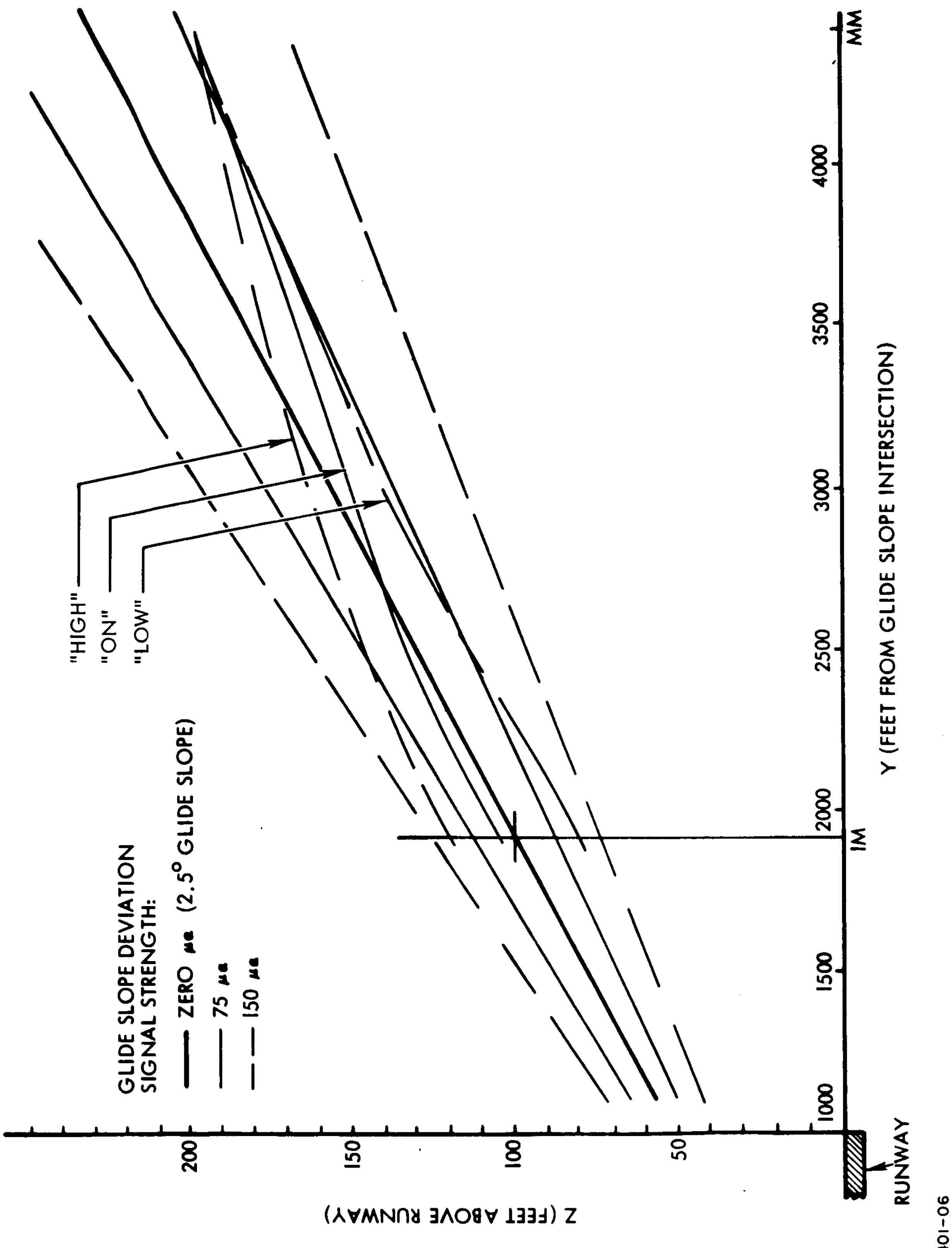

Figure 3g. Variations in vertical offset associated with a "Low" glide slope tracking history.

excessive offset conditions to provide a more complete sample of situations to be judged. A systematic procedure will be worked out for specifying the profile to be followed on each run to ensure that subjects are exposed to similar run patterns and that similar run patterns are used for alternate experimental conditions.

Controlled Variations in Environmental Conditions

Further definition of the simulated flight sequence is provided by identifying the environmental conditions to be represented. These include irregularities in terrain elevation approaching the runway, weather ceiling and runway visibility conditions, surface winds, the location and characteristics of final approach marker beacons, the approach and runway lighting system, the location and operating characteristics of ILS antennas, and runway characteristics. A brief statement of the important features and controlled variations in these conditions which are required in the recommended simulation sequence is given below:

a. Terrain elevation - controlled variations in terrain elevation approaching the runway are recommended to provide a more complete test of the subject's ability to assess relative altitude. Two variations in the comparatively level terrain situation represented by the actual approach to DIA (TP-1 in Figure 4) are recommended. One of these will be characterized by a sharp drop in terrain elevation on the approach end of the runway (TP-2 in Figure 4). With this terrain profile, absolute altitude at the decision height would be 140 feet and "arrival at the decision height", if it were judged by reference to a radio altimeter without considering the difference between absolute and relative altitude, would occur quite late in the approach. The second variation (TP-3 in Figure 4) is characterized by rising terrain off the approach

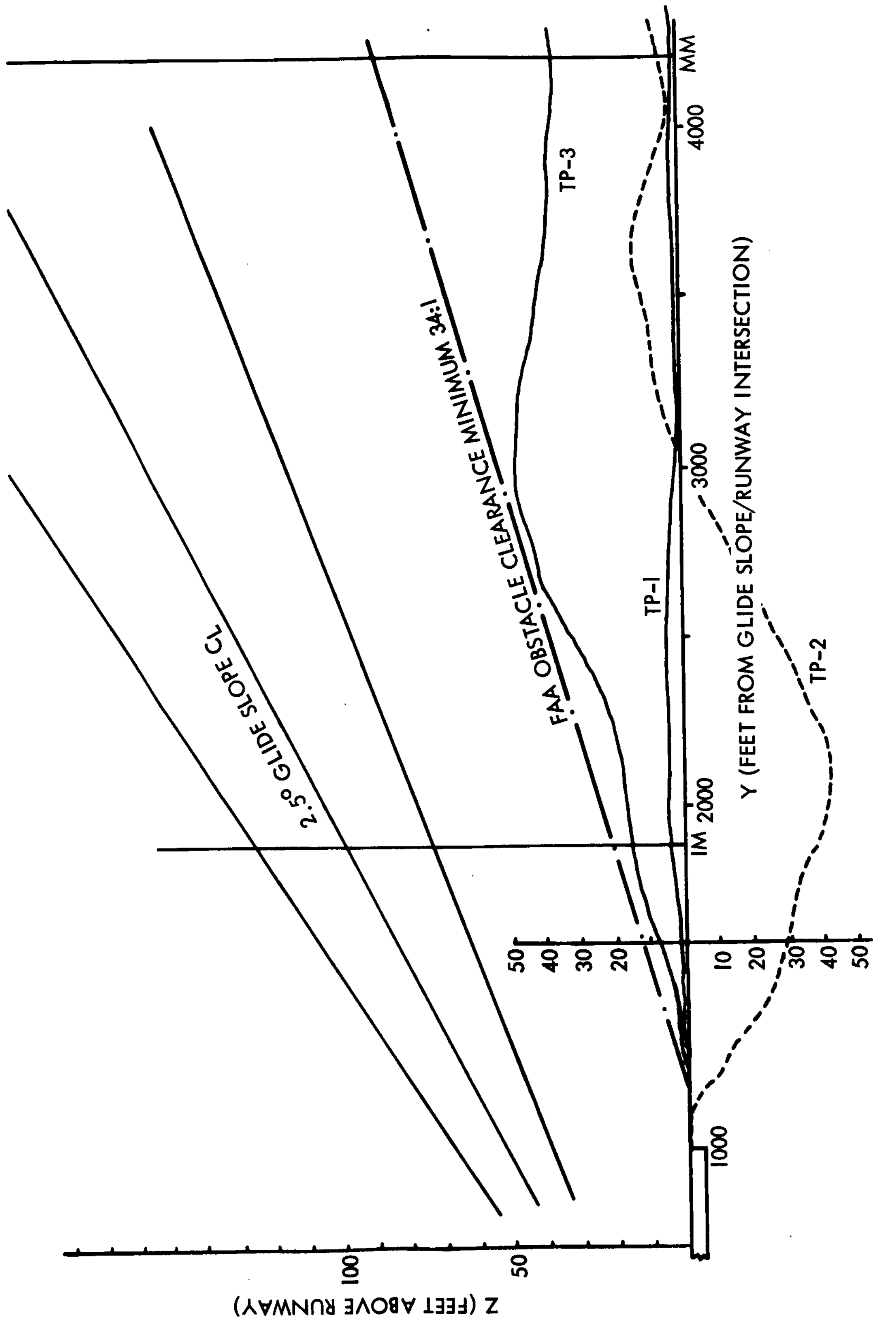

Figure 4. Variations in terrain elevation approaching runway.

end of the runway. With this terrain profile, "arrival at the decision height" again judged without explicit consideration of terrain elevation, would occur early.

b. Weather ceiling and runway visibility - on all runs, the fade-in of visual cues, representing the penetration of cloud cover in the vicinity of the runway, should occur within the decision region, i.e., between the middle marker and the decision height. To preclude the use of emerging visual cues for judging relative altitude and to vary the conditions affecting the landing commitment decision, the use of three different "break-out" altitudes within this region is recommended: 185 feet, 165 feet, and 125 feet (relative altitude). Some variation in runway visibility is also recommended by simulating runway visual range of 1200 feet on some runs and 1600 feet on others, but this variation is not considered essential.

c. Surface winds - in a related simulation study of low visibility approach and landing operations (ref. 2), significant differences in subject's ability to control the aircraft in the lateral axis were clearly indicated when the effects of a 17 knot cross wind were applied. In the recommended study, most of the runs will be made simulating automatic control on at least one axis all the way to the decision height and no simulation of wind effects will be necessary. Reports of wind conditions which are compatible with the controlled flight paths will be provided. However, some of the approaches will be made under manual control and, more important here, manual control will be assumed at the decision height and it will be of interest to examine the effects of variations in wind conditions on manual control of the landing maneuver. Simulation of three wind conditions is considered desirable: calm, 15 knot crosswind, and

10 knot tailwind. The direction of crosswind conditions can be varied to match controlled approach histories where appropriate. Selected values for wind conditions were taken from FAA Advisory Circular 20-57, dated January 29, 1968, which established environmental conditions under which touchdown limits for Category II operations apply, i.e., ". . . . Headwinds up to 25 knots; tailwinds up to 10 knots; crosswinds up to 15 knots; moderate turbulence, wind shear of 8 knots/100 feet from 200 feet to touchdown."

d. <u>Location and characteristics of final approach marker beacons</u> - representation of an outer marker beacon located 4.6 nautical miles from the runway, a middle marker at 0.6 nautical miles, and an inner marker at 0.2 nautical miles as shown in Figure 2 is recommended.

e. <u>Approach and runway lighting system</u> - a Category II visual guidance system, consisting of configuration "A" approach lights with sequenced flashing lights, high intensity runway edge lighting, touchdown zone lights, and centerline lighting should be represented.

f. <u>Location and operating characteristics of ILS antennas</u> - a Category II ILS installation should be represented with the localizer antenna array located a nominal 1000 feet beyond the far end of the runway and with the glide slope antenna located 1000 feet from the runway threshold. In the simulation sequence it can be assumed that the localizer beam is precisely aligned with the designated localizer course at DIA (006°) and that the glide slope is accurately aligned with a 3° vertical approach path. Allowable deviations in beam alignment can be considered in the analysis and interpretation of data and need not be simulated.

g. Runway characteristics - runway elevation, length, and width should be as specified for runway 1R at DIA, i.e., 313 feet MSL, 11,500 feet, and 150 feet respectively. All weather runway markings should be represented.

Experimental Tasks

The tasks to be performed by subject-pilots during the simulation sequence were derived from the analysis, in Volume II of the present study, of suspect flight management tasks associated with judging approach success and from the more complete identification of flight management task requirements distinguished earlier in Volume I. The general task assignment to subjects will be to assume full management responsibility for the approach to the decision height and then, as dictated by the outcome of approach success judgments and/or specific instructions from the experimenter, to either complete the landing under manual control or to initiate a go-around. For study design purposes and the subsequent development of simulation requirements, it is useful to distinguish two types of more specific task assignments, i.e., primary and concurrent.

Primary tasks are the suspect components of the approach success judgment and are the tasks on which data collection and analysis activities will be focused in the recommended study. Performance objectives and the factors affecting performance of these tasks must be carefully considered in the study design in order to obtain meaningful results. Concurrent tasks are the additional task requirements which must be satisfied during the simulated flight sequence and are assigned to subjects to impose more realistic task loadings. As such, they should be construed as a condition under which primary task performance will be evaluated in the study. Data on concurrent task performance will be taken only as it relates to the evaluation of primary task performance.

An outline of task assignments to the subject during the simulation sequence is given below. Tasks are identified in the general order in which they would be initiated and each task is classified as primary or concurrent. Tasks are listed by approach and landing phase segments, as defined in Volume I. The simulation sequence begins with the aircraft in the latter portion of the initial approach, at approximately 10 nautical miles from the runway, tracking inbound on the assigned localizer course, maintaining the assigned initial approach altitude, and decelerating to a pre-selected final approach airspeed. Baseline conditions are assumed, i.e., flight control is automatic and fully coupled to ILS guidance signals.

Initial Approach

1. Receive and acknowledge final approach clearance and control transfer instructions (concurrent)
2. Adjust desired airspeed as required and assess autothrottle control (concurrent)
3. Assess localizer tracking (concurrent)
4. Assess altitude control (concurrent)
5. Complete final landing check (concurrent)
6. Monitor operating status of critical components of the landing system and adjust operating modes as required (concurrent)
7. Monitor glide slope acquisition (concurrent)
8. Establish final flap settings and check trim condition (concurrent)
9. Monitor initiation of glide slope capture maneuver (concurrent)
10. Adjust command airspeed for final approach (concurrent)

Final Approach

1. Receive and acknowledge landing clearance, traffic advisories, surface winds, altimeter settings, and runway condition reports from local control (concurrent)

2. Assess execution of glide slope capture maneuver (concurrent)

3. Continue to monitor glide slope and localizer tracking (concurrent)

4. Continue to monitor autothrottle control of airspeed (concurrent)

5. Continue to monitor landing system operating status (concurrent)

6. Assess aircraft attitude and rate-of-descent (concurrent)

7. Assess relative altitude (height above touchdown zone) as aircraft descends through 300 feet, 200 feet, and approaches the 100 foot decision height (primary)

8. Assess flight path alignment with the runway as the aircraft approaches the decision height (primary)

9. Assess adequacy of external visual reference as the aircraft approaches the decision height (concurrent)

10. Monitor arrival at the decision height (primary)

11. Assess touchdown position along runway (primary)

12. Resolve landing commitment decision (concurrent)

Landing

1. Check trim condition and disengage automatic flight control system (concurrent)

2. Assume full manual control and execute landing maneuver or initiate missed approach maneuver (concurrent)

Subject Selection and Task Orientation

Subject selection and the orientation they are given with respect to how the experimental tasks are to be performed will be governed by two general considerations. The major consideration, as indicated earlier, is the requirement for subject behavior in the simulation sequence to be sufficiently representative of SST command pilot behavior to permit some generalization of study results to this target population. There is, of course, no existing population of SST command pilots to draw subjects from and detailed procedures for carrying out SST flight management responsibilities have not yet been formulated. The target population is closely approximated, however, by senior pilots with experience and training in flight management responsibilities in current jet transport operations.

The plan, then, will be to use airline pilots currently qualified as Captains or Senior First Officers as subject-pilots in the study. Aspects of task performance which are SST-peculiar or specific to the conditions simulated will be presented to subjects in special briefings and simulation familiarization exercises prior to the conduct of experimental runs. These subject preparation exercises will be designed to establish a common understanding of the tasks to be performed, the manner in which the flight situation and environmental conditions are simulated and the operating techniques and procedures to be employed. This commonality in subject orientation to assigned tasks will satisfy the second general consideration, namely that the potential effects of individual subject differences in task performance on study results should be minimized.

Task performance factors to be considered in subject selection and preparation exercises include:

a. SST performance data, AFCS operating modes, autothrottle operation, display functions, fault monitoring and warning/status displays, etc.

b. FAA-defined operating criteria and requirements for Category II operations, including approach success criteria.

c. Simulated ILS installation and operating characteristics.

d. Simulated runway characteristics and approach terrain profiles.

e. Runway perspective and approach light configuration as they would appear from the 100 foot decision height with various flight path offsets and tracking vectors.

f. Operating procedures to be followed appropriate to each experimental condition.

Experimental Design

The design of the recommended study is best understood as a composite structure comprised of three separate and distinguishable component experiments which can all be carried out within the context of the same set of simulated approach and landing sequences. Its basic structure, as schematized earlier in Figure 1, is simply a testing sequence wherein a number of subjects are exposed to controlled variations in aircraft behavior and environmental conditions and data is taken on their performance of specified flight management tasks. All of the runs in this testing sequence are made under the same baseline conditions of information availability and display, operational procedure, and control task loading.

Intersubject differences in performance are not of primary interest in this testing sequence and no examination of differences in performance under alternative experimental conditions is provided for in this basic "design". Performance data obtained on components of the approach success judgment will be interpreted with reference to external criteria of accuracy, timeliness, appropriateness, etc. For example, the accuracy of cross-track position judgments will be assessed by comparing subject estimates of this parameter value with the "actual" position of the aircraft at selected points in the simulation sequence. The average magnitude and variability of these "error" scores, taken on all subjects over all controlled variations in flight path and environmental conditions, will then be interpreted with regard to the practical significance of errors as great as those reflected in the data and/or the proportion of runs on which errors in judgment were indicated. Some manipulation of the data will be possible which will reveal differences, if any in the effects of flight profile variations on subject performance, but no rigorous statistical comparisons are considered necessary and provisions for making such comparisons are not included in the basic design.

However iterations of this testing sequence are recommended in order to examine the effects of differences in crew procedures and control task loading. This examination does entail a statistical assessment of differences in flight management performance under alternative conditions and may be construed as the second experiment in the composite design. Including baseline conditions, three operational procedures and three control task loadings were distinguished, as outlined below, to define the experimental variables.

Operational Procedure

1. Cross-check - Experimental tasks are initially performed solely by instrument reference. As the aircraft approaches the anticipated breakout altitude, and at his discretion, the Captain looks out to see if the runway or approach lights are visible. As visual cues become available, the Captain begins to replace or supplement information obtained by instrument reference with information from the external visual field. The frequency and duration of shifts in visual reference are at the Captain's discretion. Full control authority is retained by the Captain throughout the approach and landing sequence.

2. Head-down - Under this procedure, the Captain elects to perform assigned experimental tasks solely by instrument reference all the way to the decision height and relies on the First Officer to monitor external visual conditions. The First Officer will report on the acquisition of visual reference in accordance with a pre-determined communications procedure, e. g., he may call out such reports as "Approach lights in sight to the right" or "Runway in sight." As a matter of discipline in operating procedure, the Captain will not look up for visual cues until the First Officer reports adequate visual reference. If the report is received prior to reaching the decision height, the Captail will look up, resolve the landing commitment decision, and then either continue the approach or initiate a missed approach procedure.

3. Head-up - Under this procedure, control authority is assigned to the First Officer and the Captain concerns himself exclusively with managing the approach. As a matter of discipline, the First Officer remains head down to closely monitor autopilot performance or exercise manual control. At a pre-determined altitude, the Captain elects to go head-up and to direct his full attention to the search for visual cues.. When he is satisfied with the approach and the visual cues available for landing, the Captain will assume control authority and continue the approach. If this control take-over does not occur by the time the decision height is reached, the First Officer initiates the missed approach procedure by instrument reference.

Control Task Loading

1. Fully coupled - The Automatic Flight Control System (AFCS) is engaged in the AUTO LAND mode and is automatically tracking both the glide slope and localizer beams.

2. Split axis - The AFCS is engaged in the roll axis only and localizer tracking is automatic; vertical flight path control (pitch axis) is manual.

3. Fully manual - The AFCS is disengaged (except for stability augmentation) and both horizontal and vertical flight path control is manual.

By combining the operational procedures and variations in control task loading just outlined, nine experimental conditions can be distinguished. However, the "Head-up" procedure cannot meaningfully be associated with differences in control task loading because control authority must be assigned to the First Officer when this procedure is adopted. Otherwise, the "Head-up" condition would be indistinguishable from the "Cross-check" procedure. In terms of its representation in the simulation sequence, the assignment of control authority to the First Officer can be seen as assuming a "Fully coupled" control condition when the "Head-up" procedure is used. Seven experimental conditions remain:

1. "Cross-check" procedure paired with "Fully Coupled" control (baseline condition)

2. "Cross-check" procedure paired with "Split Axis" control.

3. "Cross-check" procedure paired with "Fully Manual" control.

4. "Head-down" procedure paired with "Fully Coupled" control.

5. "Head-down" procedure paired with "Split Axis" control.

6. "Head-down" procedure paired with "Fully Manual" control.

7. "Head-up" procedure paired with "Fully Coupled" control.

The design for this second experiment will be a modified three by three factorial design with repeated measures on one factor. This design is schematized in Figure 5. Only three groups of subjects are required in this design and this should permit important economies in subject numbers and time commitments to the project. The same n subjects in Group 1 and 2 are observed under all levels of control task loading, but only under two levels of operational procedure, i.e., a_1 and a_2 respectively. Subjects in Group 3 are observed only under treatment combination a_3b_1, since additional observations under the remaining levels of Factor B are not meaningful. Using this design, comparisons between different levels of Factor A are confounded with differences between groups of subjects. However, the effects of Factor B and of interactions between Factor A and B will be free of this confounding and tests of these effects will be considerably more sensitive than those on the effects of Factor A.

Each of the n subjects within the three groups will be exercised on all appropriate variations in flight profiles. The order in which these profiles are presented will be randomized, as will the order in which subjects are exposed to different levels of Factor B, to minimize carry-over effects from one simulation run to the other. These effects include such influences as fatigue, feedback received on performance in preceding runs, and commonalities in situations being judged.

Data on all component approach success judgments and the "actual" flight situation, as it develops under the particular flight profile and environmental conditions simulated, will be taken on each run. Appropriate variance analyses will then be conducted in order to examine differences in the effects of each of the seven experimental conditions on criterion measures of the accuracy, timeliness, and reliability of:

a. relative altitude judgments,
b. cross-track position judgments,
c. tracking vector judgments, and
d. touchdown position judgments.

FACTOR B
TASK LOADING

FACTOR A OPERATIONAL PROCEDURE	B_1 (FULLY COUPLED)	B_2 (SPLIT AXIS)	B_3 (FULLY MANUAL)
A_1 (CROSS-CHECK)	GROUP 1	GROUP 1	GROUP 1
A_2 (HEAD - DOWN)	GROUP 2	GROUP 2	GROUP 2
A_3 (HEAD - UP)	GROUP 3		

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Figure 5. Schematic representation of the design for the second experiment.

The third experiment in the composite design is directed toward the problem of establishing appropriate lateral offset limits at the 100-foot decision height and to the issue of relating variations in the vertical flight situation to touchdown performance relative to longitudinal dispersion limits. As a consequece of exercising control over the flight paths followed by the simulated aircraft on most of the runs conducted for purposes of experiments one and two, touchdown performance associated with a wide range of terminal conditions (i. e., vertical offset, lateral offset, and tracking vector at the decision height) can be examined. Subjects will be instructed to attempt the landing maneuver on all runs except those on which the approach success and/or landing commitment decision is clearly negative. For purposes of the experiment, subjects will be further instructed not to compromise on desired touchdown rate-of-descent in attempts to assure touchdown within established longitudinal limits nor to use control techniques that could not be used routinely under actual Category II flight conditions (e. g., the "duck-under" maneuver or the use of excessive roll rates and/or bank angles).

With respect to the lateral offset limit problem, this third experiment can be seen as a parametric study of the subject-pilot's ability and/or willingness to execute the side-step maneuver from various lateral offset positions at the decision height. The controlled flight profiles defined in Figure 3, will provide for an examination of lateral touchdown performance (in terms of both deviation from the runway centerline and cross-track velocity) as a function of the following values of lateral offset and tracking vector at the decision height:

a. 40 feet left/parallel (Profile P-1)
b. 60 feet left/converging (Profile P-5)
c. 150 feet left/diverging (Profile P-9)
d. 10 feet right/diverging (Profile P-4)
e. 60 feet right/parallel (Profile P-8)
f. 135 feet right/converging (Profile P-3)
g. 25 feet left/converging (Profile P-7)
h. 70 feet left/diverging (Profile P-2)
i. 110 feet right/parallel (Profile P-6)

Data on landings made from lateral offset positions resulting from manually controlled approaches will also be available for analysis. Touchdown limits established in a recent FAA Advisory Circular (AC 20-52, dated January 29, 1968) will be used to evaluate the success of landing maneuvers attempted from the various offset conditions. In this document, lateral touchdown dispersion limits are set at ± 27 feet from the runway centerline on a two-sigma basis. It is anticipated that the range of offset values examined will include decision height situations from which this touchdown requirement cannot be satisfied. Based on the data obtained, the maximum decision height offset distance from which successful landings can be accomplished may be taken as an appropriate criterion value for judging flight path alignment as the aircraft approaches Category II minimum altitude.

The examination of touchdown performance relative to longitudinal dispersion limits is included as an empirical test of the subject-pilot's ability to judge his anticipated touchdown position on the basis of vertical situation data available to him at the decision height. It is not primarily concerned with determining vertical offset positions from which a touchdown within these limits can be accomplished. In the discussion of the problem of assessing vertical flight path alignment in Volume II of this study, it was suggested that unacceptably long touchdowns -- possibly beyond the 3000 foot touchdown zone -- could occur even with no significant vertical offset at the decision height. In the recommended simulation sequence, subject estimates of touchdown position made at the decision height will be compared with actual touchdown performance in order to determine the degree of correspondance between the two.

Longitudinal touchdown dispersion limits established in AC 20-57 will again be used to assess touchdown performance, principally the "far limit", i.e., a touchdown position which will enable the pilot ". . . to see at least four bars (on 100 foot centers) of the 3000 foot touchdown zone lights at touchdown." It is understood that touchdown performance will be a function of wind conditions and pilot control technique in executing the flare maneuver as well as initial offset and airspeed conditions at the decision height. Wind conditions and initial conditions at the decision height will be controlled and recorded for each landing sequence. Subject-pilot control technique will vary, of course, but familiarization with the task and special instructions are expected to establish a common task orientation. Care will be taken to insure that subjects understand that system performance under the conditions simulated, and not individual pilot performance, is of interest in the study and that undue effort to demonstrate that touchdowns can be accomplished within established limits (e.g., by executing a "duck-under" maneuver or by deliberately accepting a somewhat harder landing rather than landing a bit longer) is not appropriate to experimental task performance. On the other hand, no artificial constraints on pilot behavior will be imposed. The timing of flare initiation and control techniques used to reduce rate-of-sink to acceptable touchdown values will be entirely at the discretion of the subject-pilot.

Throughout the landing maneuver, data reflecting aircraft attitude, airspeed, relative altitude, and rate-of-descent will be recorded. The application of unusual control techniques in either vertical or horizontal flight path control should thus be apparent and can be considered in the interpretation of touchdown performance data. Documentation of the third experiment will be a matter of reporting touchdown performance as a function of variations in the flight path situation at the decision height, environmental conditions (notably winds), and the component assessments of approach success obtained from the subjects during the approach to the decision height. Analysis and interpretation of these data is expected to:

1. identify lateral flight path offset conditions from which pilots are unwilling to attempt the landing and/or are unable to satisfy lateral displacement limits at touchdown, and

2. to reveal any systematic correlation between subject-pilot judgments and/or confidence at the decision height that a soft touchdown can be accomplished within longitudinal dispersion limits and the actual outcome of the landing maneuver.

SIMULATION REQUIREMENTS

A successful implementation of the recommended simulation study, as outlined in the foregoing plan, will entail special consideration of two important simulation requirements. One of these is the requirement for representing information availability and display characteristics in the simulation in such a way that the information processing demands of experimental tasks do not differ significantly from those associated with actual task performance in the baseline SST landing system. The general usefulness of study results in forecasting potential SST operating problems will be a direct function of how well this requirement is satisfied.

The second important requirement to be satisfied is the simulation of the effects of automatic flight path control and automatic control of airspeed. Automatic flight control in both the pitch and roll axes and autothrottle control of airspeed are assumed to be the primary operating mode for SST approach and landing operations. Deviations from this control mode, as indicated by the inclusion of variations in flight control mode as an experimental variable in the recommended study, can be expected to impose different task loadings on the pilot. Again, the applicability of study results to SST operating problems will be impaired if this study requirement is not met.

In this section, a more complete statement of these simulation requirements is given in order to establish additional guidelines for the subsequent detailed specification of simulation equipment and procedures to be used in carrying out the recommended study. Emphasis is given to a delineation of the requirement for simulating SST information availability and display characteristics as envisioned for the baseline Low Visibility Landing System (LVLS). A brief discussion of the requirement for simulating automatic control functions is then presented.

Simulation of SST Information Availability and Display Characteristics

The identification of potential problems in supporting SST command pilots in the performance of flight management tasks was based on an analysis of the information processing demands of component cognitive processes. These information processing demands were distinguished in Phase II of the study (ref. 1) by examining the information expected to be available to the SST Captain and the sources of this information (e.g., flight deck instruments, communication inputs, flight planning materials, recall of procedures, etc.) in the baseline LVLS. It will be recalled that potential problems areas, including the ones selected for consideration in the recommended study, were identified when this examination disclosed such conditions as the following:

a. Significant conditions and events, which must be assessed within severe time constraints, are not directly represented in the SST display system.

b. Displays are available from which significant conditions and events can be inferred, but the information processing involved would take too long, be subject to unacceptable error probabilities due to inaccuracies in source data or the low reliability of processing steps, or be subject to distortion or bias due to the stress of task conditions.

c. Criterial information, required to assess the significance or character of available information on aircraft and environmental states, is not expected to be available or it is not expected to be available in a form appropriate to the assessment task.

d. Low or negative pilot acceptance of an information source can be anticipated.

The point of the foregoing is that the problems being investigated in the recommended study are actually defined in terms of information availability and display characteristics in the baseline LVLS. In the simulation, the representation of information availability and display characteristics associated with the experimental task must be carefully considered to ensure that these problems do not become re-defined. Insofar as it is practicable, the same information must be provided to subject-pilots as that available in the baseline LVLS, and it must be presented to subjects in the same form.

This general simulation requirement is elaborated in Table 2. Information items expected to be available to the SST command pilot are listed in the first column. Entries in this column are intended to refer to the stimulus materials, conditions, and events which, in actual SST approach and landing operations, are expected to govern the performance of the primary and concurrent experimental tasks cited in an earlier section. The items should be understood in terms of their referents and not in terms of how they may be displayed to the pilot.

In the second column of Table 2, the form in which each information item is expected to be available to the SST command pilot in the baseline LVLS is characterized in terms of display mode and amplifying comments. Five basic display modes and three special categories of information availability were distinguished to account for important differences in how the various information items are expected to be available. For the subsequent determination of appropriate means for representing these information items in the simulation sequence, important differences are those associated with differences in input processing requirements imposed on the pilot.

A brief interpretation of the entries used in the second column is given below:

Direct visual display - The information item, as specified, is directly available by visual reference to a flight deck instrument. Significant characteristics of this display are given in amplifying comments.

Indirect visual display - The information item, as specified, is not displayed, but can be derived from the direct visual display of related parameters.

Auditory signal - An aural signal other than speech is used to represent the item referent, e.g., a tone, buzzer, bell, etc.

Radio voice communication - The information item is a voice communication, either broadcast on monitored radio frequencies or specifically addressed to the flight.

Flight reference data - The item is recorded on special data sheets or available on published charts, maps, route manuals, performance guides, etc., available to the crew during the flight.

None, directly perceived - There are no displays available for the item referent, either direct or indirect; however, the designated condition or event can be directly perceived on the basis of visual, auditory, tactual, or kinesthetic cues.

None, learned procedure - The information is available to the crew only through recall of previously acquired training and experience; no display or documentation of the designated procedure is used.

None, perceptual expectancy - This category is similar to "learned procedures" in that crew access to the information is by some form of recall. In this instance, however, prior experience and/or training in how a designated aspect of the flight situation should appear, feel, sound, etc., is "recalled" rather than knowledge or information.

Table 2

DELINEATION OF SIMULATION REQUIREMENTS

INFORMATION ITEM	AVAILABILITY IN BASELINE LVLS
1. Approach clearance	Radio voice communication - received from local approach control facility. Pilot may record key elements on a flight data sheet. Communication of approach clearance occurs prior to the starting point in the planned simulation sequence and contains such information as holding pattern assignment, ILS runway in use, other traffic, surface winds, visibility restrictions (RVR) and assigned time and entry point to ILS approach.
2. Assigned approach profile	Flight reference data - pilot obtains from approach chart and/or recall from previous experience. See approach plate to Dulles (Figure 2).
3. Assigned initial approach altitude	Flight reference data - pilot obtains assigned value from approach chart. Category II approach altitude to Dulles is listed as 1600 feet (MSL).
4. Optimum initial approach airspeed	Direct visual display - pilot obtains computed value from the Flight Engineer by voice communication or via a hand written card. The pilot adjusts an index on the edge of the airspeed indicator to establish a relative position display (i.e., aircraft speed relative to desired speed). Under autothrottle conditions the desired value is input to the AFCS and indicated by a digital readout on the AFCS panel. Initial approach airspeed is primarily a function of aircraft landing gross weight. A nominal value of ± 160 knots will be used in simulation.
5. Assigned initial approach course	Direct visual display - pilot obtains assigned value from an approach chart and sets a bug on the horizontal situation indicator (HSI) which provides him with a relative position display of the assigned course. Desired course may also be

Table 2 (Continued)

INFORMATION ITEM	AVAILABILITY IN BASELINE LVLS
	input to the AFCS and would then be indicated by a digital readout on both the HSI and AFCS control panel.
6. AFCS operating mode	Direct visual display - annunciators indicate engagement status of the autopilot and autothrottle systems. Position and labelling of AFCS mode selection controls present operating mode. Autopilot and autothrottle disconnect annunciators are available within the optimum viewing area on the instrument panel (defined as within $\pm 15^{o}$ lateral and 30^{o} below most frequent fixation point).
7. Wing flap position	Direct visual display - a digital readout of wing flap position in degrees is available on the pilot's center panel.
8. Landing gear position	Direct visual display/auditory signal - color coded annunciators on the pilot's center panel indicate the position of the nose gear, main gear, and gear doors. An audio warning signal is also provided to indicate that the aircraft is in the landing mode without all gear down and locked.
9. Pre-landing check procedures	Flight reference data - available in checklist form, however, input to Captain is typically direct voice communication from First Officer.
10. LVLS operating status	Direct visual display - LVLS operating status is displayed to the pilot by a master warning light, a system annunciator panel, an instrument annunciator panel, and by control positions and labelling on the AFCS control panel.
11. Airspeed	Direct visual display - pilot obtains airspeed from an Equivalent Airspeed (EAS) indicator which provides both a relative position display and a digital readout of airspeed. A fast slow indicator showing actual airspeed relative to the selected autothrottle reference airspeed is available on the Attitude-Director Indicator (ADI).

Table 2 (Continued)

INFORMATION ITEM	AVAILABILITY IN BASELINE LVLS
12. Relative altitude	Indirect visual display - altitude relative to runway elevation is not directly represented but can be estimated from absolute (radio) altitude and/or pressure altitude and reference to the approach chart profile. Pilot reads pressure altitude on the barometric altimeter which provides both a relative position and a digital readout of altitude above mean sea level. Absolute altitude is available on a radio altimeter with a manually setable index which may be used to indicate radio altitude at the decision height.
13. Vertical velocity	Direct visual display - pilot reads vertical velocity from a relative position display of instantaneous vertical speed. Command vertical velocity may also be available as a digital readout associated with a directional symbol, i.e., pointing up or down.
14. Attitude and attitude rates (pitch and roll)	Direct visual display - pilot obtains this information from a conventional Attitude-Director Indicator. Flight director information (pitch and roll commands) is integrated with the ADI and is selectively available.
15. Localizer deviation	Direct visual display - localizer deviation is qualitatively presented on a conventional localizer deviation indicator with ± 2 dots displacement corresponding to a ± 150 microamp deviation signal. An expanded localizer deviation indicator is also available with a full (one dot) deflection representing a deviation signal of approximately ± 37 microamps. The relationship between indicated deviation and actual lateral offset from extended runway centerline in feet, for an 11,500 foot runway, is presented in Figure 3.
16. Glide slope deviation	Direct visual display - glide slope deviation is qualitatively presented on a glide slope deviation indicator with ± 2 dots representing a ± 150 microamps deviation signal. The relationship between indicated deviation and actual offset from a 3° glide slope in feet is presented in

Table 2 (Continued)

INFORMATION ITEM	AVILABILITY IN BASELINE LVLS
	Figure 3 for the approach to 200 feet. Below 200 feet, glide slope deviation signals are attenuated as a function of radio altitude and indicated glide slope deviation is then directly proportional to offset distance in feet.
17. Pitch steering commands	Direct visual display - pilot monitors relative position pitch steering commands on the ADI. It does not indicate actual pitch relative to desired, but a command to continue pitch attitude in the indicated direction.
18. Bank commands	Direct visual display - bank commands are also displayed using a relative position flight director element on the ADI.
19. Heading	Direct visual display - pilot reads heading on a radio magnetic indicator integrated with the HSI which has a fixed pointer and a movable scale.
20. Aircraft arrival at the outer marker	Direct visual display and auditory signal - an indication of arrival at the outer marker is provided by the illumination of an annunciator and by a coded auditory signal received via the pilot's headset.
21. Glide slope capture	Direct visual display - this event is indicated by an annunciator element of the approach progress display changing from amber to green. It may also be inferred from the behavior of the flight director pitch command bar, changes in pitch attitude and vertical speed, and from the glide slope deviation indicator.
22. Optimum final approach airspeed	The entry for item 4 is applicable here. Nominal SST approach speed is estimated to be 127 knots for a normal landing gross weight.
23. Optimum approach vertical speed	None, learned procedure - pilot recalls the desired value from training and past experience. Nominal rate of descent is approximately 600 fpm.

Table 2 (Continued)

INFORMATION ITEM	AVAILABILITY IN BASELINE LVLS
24. Cross-track position	Indirect visual display - pilot can estimate cross-track position from localizer deviation indications. External visual reference may be used if visibility permits.
25. Cross-track velocity	None, directly perceived - direct observation of position relative to runway and/or approach lights, visibility permitting. May be inferred from rate-of-change in indicated localizer deviation.
26. Flight path - runway alignment (tracking vector)	None, directly perceived - direct observation of runway and/or approach lights, visibility permitting. May be inferred from indicated localizer deviation, heading, and reference to or recall of assigned localizer course.
27. Trim condition	Direct visual display - pilot can determine trim settings directly from the position and labelling of trim controls. Out-of-trim conditions or malfunctions in automatic trim control are input via voice communication from the Flight Engineer who has access to a display of all movable control surfaces.
28. Aircraft arrival at the decision height	Direct visual display - arrival at the decision height is directly displayed by a minimum altitude light driven by the radio altimeter and by the illumination of the inner marker beacon light, assuming that an inner marker is installed at the proper position. It may also be determined by reference to the pre-set relative altitude index on the radio altimeter.
29. Landing clearance	Radio voice communication - received from local control (tower operator).
30. Approach success criteria	None, learned procedure - recall of approach success criteria from training and past experience. Airline S. O. P. 's and FAA criteria for continuing Category II approach, as outlined in FAA Advisory Circular 120-20 and 20-57, are the sources of these criteria.

Table 2 (Continued)

INFORMATION ITEM	AVAILABILITY IN BASELINE LVLS
31. Absolute altitude at the decision height for the destination airport	Flight reference data - obtained from the published Category II approach chart or recall from past experience. Pilot may enter this value on the radio altimeter using index bug.
32. Surface winds/gust conditions	Radio voice communication - received from local control. Pilot may also infer cross winds from aircraft heading and localizer tracking displays and gust effects from vehicle accelerations.
33. Runway condition	Radio voice communication - pilot obtains runway condition information via radio voice communications with local control. Also recalls more stable conditions from flight planning and pilot reports.
34. Aircraft position relative to the runway threshold	None, directly perceived - direct observation of runway and/or approach lights. May be inferred from reference to localizer and glide slope deviation and estimates of position relative to marker beacons.
35. Optimum flare altitude	None, perceptual expectancy - previously acquired familiarity with how correct flare initiation altitude "looks", particularly with respect to height above touchdown zone and flight deck position relative to main gear location. Recall of recommended flare altitude and reference to radio altimeter could be used.
36. Touchdown	None, directly perceived - pilot determines touchdown by feel and by reference to visual cues.
37. Position on runway at touchdown	None, directly perceived - direct observation of runway touchdown zone markings and/or runway lighting.

The characterization of information availbility and display characteristics in Table 2 will be used, together with the controlled variations in environmental conditions identified earlier and the control functions outlined below, in subsequent determinations of the specific means for their representation in the recommended simulation study. In selecting and/or developing the particular simulation equipment and materials to satisfy these requirements, the concept of "functional equivalence" developed in an earlier Serendipity study (ref. 3) will be applied. The reader is referred to the referenced document for a discussion of this concept, but in general it is concerned with the fidelity or degree of "realism" considered necessary in the simulation. For example, a high degree of physical fidelity in representing crew information inputs (i.e., using the same flight instruments as those expected to be installed in the SST) is not considered essential. Functionally equivalent representations of required information items can be achieved by using simulated flight deck displays which adequately match the mode of presentation and display characteristics outlined in Table 2.

Simulation of Automatic Flight Path and Airspeed Control

An adequate simulation, in baseline runs, of localizer and glide slope tracking under fully-coupled AFCS control is required for two reasons. As indicated earlier, this is the primary operating mode of the projected SST LVLS and any deviation from this control mode can be expected to impose different control task loadings on the subject-pilot than those envisioned for the actual situation. When manual control is exercised on one or more control axes, the Captain can be expected to have less time and attention to apply to the performance of flight management tasks.

The second reason for simulating AFCS control of localizer and glide slope tracking is that control is thereby gained over the "actual" flight path of the simulated aircraft. This is an especially desirable feature in the recommended study wherein the subject's ability to assess various aspects of the ongoing flight situation are of interest. Exercising this control, subjects can be exposed to the same flight situations for judgment and the same variations in flight path and enviornmental conditions can be consistently represented from one data collection opportunity to the other. Under manual control, only a limited sample of flight situations would be available for judgment and the effects of differences in individual subject performance of the control task on flight management would be difficult to sort out in the analysis and interpretation of study results.

The general requirements for simulating automatic flight path control are established by the flight profiles defined in Figure 3. On baseline runs and on all iterations which call for automatic control on one or both axes, the simulated flight sequence should follow the designated profiles as if the indicated excursions from the localizer course and/or the three degree glide slope were the outcome of AFCS control. Particular profiles will be designated for each run in accordance with the experimental design. It has already been noted that some of these profiles represent degraded control system performance in that somewaht excessive departures from tight ILS tracking are apparent. These "marginal" and "excessive" deviations from optimum tracking were deliberately included to provide a more complete set of flight situations to be judged.

For the purposes of the recommended study, it is not considered necessary to simulate the operating characteristics of any particular automatic flight control system. In piloted flight simulators used in conjunction with visual flight attachments, such as the GPS and Redifon systems at Ames, requirements for automatic flight path control might be met by programming the position of the TV camera and associated optical attachment relative to the terrain model to conform to the position plot called for in the designated profile, i.e., by programming cross-track position (X axis) and relative altitude (Z axis) as a function of forward movement over the terrain model at the appropriate speed (Y axis). The critical constraint to be satisfied, by whatever means are employed, is that simulated flight deck displays and external visual cues behave as if the aircraft were following the designated profile.

Simulation of autothrottle control of airspeed is desirable but less critical to the achivement of study objectives. Close monitoring of airspeed is considered necessary for both automatic and manual control and deliberate changes in airspeed during the approach must be manually commanded, using a slewing switch, even when the autothrottle is engaged. Control task loadings during the approach to the decision height are thus not expected to be significantly different when manual control is exercised. However, the control of airspeed using a manually adjusted index "bug" or a slewing control to command airspeed changes does entail differences in operating technique.

In view of the fact that almost all of the Category II landing system configurations include some type of autothrottle control, it is desirable to represent this control technique in the simulation study. Again, a high fidelity simulation of the response characteristics of particular autothrottle sytems is considered unnecessary. The general requirement can be satisfied by maintaining pilot-selected indicated airspeeds to within plus or minus five knots.

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